APPENDICES FOR THE ASSESSMENT OF IMPERIAL IRRIGATION DISTRICT'S REASONABLE AND BENEFICIAL USE OF WATER

NATURAL RESOURCES CONSULTING ENGINEERS, INC.®
Civil, Environmental, and Water Resources Consultants

NRCE®

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Natural Resources Consulting Engineers, Inc.
Background Information

1. NATURAL RESOURCE CONSULTING ENGINEERS

A. Introduction

Natural Resources Consulting Engineers, Inc. (NRCE) is a civil, environmental, and water resources consulting firm that provides a wide variety of professional services. Dr. Woldezion Mesghinna formed NRCE in 1989 after seventeen years of domestic and international experience. NRCE is comprised of technical professionals highly experienced in diverse areas of science and engineering. While our expertise has historically focused on water resources, we also support a wide variety of related disciplines with specialized skills in addressing environmentally related business concerns.

NRCE is engaged in all levels of project development, management, and design, from preliminary data collection to construction management, and all services are customized to meet client demands ranging from appraisal-level feasibility studies to detailed engineering design reports, investigations, and expert witness testimony. NRCE has a successful history working on high profile, diverse, and complex projects. Areas of expertise include evaluation and water rights quantification of groundwater and surface water resources, assessing water use irrigation and drainage design, and the analysis of environmental impacts.

NRCE utilizes Computer-Aided Drafting (CAD) and a Geographic Information System (GIS) to produce professional plans, maps, and decision support information. The company has both acquired and developed a variety of sophisticated computer models used for hydrologic and hydraulic modeling, groundwater analysis, and system design.

B. Technical Services

1. *Irrigation and Drainage Design Management*

NRCE staff members possess a high level of expertise in irrigation and drainage design and management. We perform engineering services related to:

- Soil Survey and Land Classification Evaluations
- Climate-Soil-Crop-Water Interaction Studies
- Quantifying Irrigation Diversion Requirements
- Irrigation Scheduling and Crop-Yield Modeling
- Salinity Effects on Crop Water Use and Crop Yield
- Gravity, Sprinkler, and Drip Irrigation Systems
- Surface and Subsurface Drainage Systems
- Design of Conveyance and Distribution Systems
- Canal System Operation and Management Studies
- Irrigation Project Feasibility and Improvement Studies
- Water Use Estimation

2. *Water Resources Evaluation*

NRCE provides surface and subsurface hydrologic evaluation for design, construction, operation, and litigation purposes.

- Data Collection Network Design and Installation
- Climatic and Streamflow Depletion and Natural Flow Analysis
- Watershed Runoff and Streamflow Modeling
- Prediction of Stream Flows for Ungaged Sites
- Flood and Drought Frequency Analysis
- Groundwater Yield Evaluation and Well Design
- Groundwater Quality and Seepage Analysis
- Water Supply System Analysis

3. *Water Quality and Environmental Studies*

Many water resource issues involve water quality and environmental components. NRCE's environmental engineers and scientists perform water quality and environmental assessments including:

- Water Quality Data Collection and Analysis
- Surface Water Flow and Contaminant Transport Modeling
- Groundwater Flow and Contaminant Transport Modeling
- Stormwater Management and Drainage Studies
- Engineering and Design Services Related to Waste Permitting
- Project Management for Treatment and Monitoring Programs
- Water and Wastewater Treatment and Design
- Remediation Plans
- Stream and Lake Quality Studies

4. *Hydraulic Design and Study*

NRCE provides complete analytical and design services for conveyance structures, dams, reservoirs, and water supply and drainage systems.

- Conveyance System Evaluation and Design
- Steady and Unsteady Flow Analysis
- PMF Estimate and Dambreak Analysis
- Reservoir Routing and Operation Analysis
- Floodplain Delineation and Management
- Hydropower Hydraulic Design and Evaluation
- Dam, Reservoir, and Ancillary Structure Design
- Flood Control Structure Design
- Groundwater Well Location and Network Design

5. *Numerical and Computer Model Studies*

NRCE scientists and engineers have extensive numerical and computer modeling experience in civil, water resources, and environmental engineering. These include surface water models such as HEC-1 through HEC-6, groundwater flow and contaminant transport models Sutra, ModFlow, HST3D, as well as custom designed models for specific detailed analysis.

- Hydrological and Hydraulic Routing
- Streamflow and Reservoir Routing
- Sediment Transport, Scour, and Deposition
- Surface Water Flow and Contaminant Transport
- Groundwater Flow and Contaminant Transport
- Reservoir System Operation and Optimization
- Optimal Water Resources Allocation Models

6. *Construction Management*

NRCE assists clients in contractor selection, construction monitoring, preparation of as-built reports and operation manuals, and compliance with regulatory requirements.

- Construction Management and Inspections
- Project Management and Supervision
- Bid Advertisements, Evaluation, and Award
- Construction Observation and Monitoring
- Progress Reporting and As-built Reporting
- Operation and Management Manual Preparation

NRCE realizes that determining the site-specific aspects of a particular reclamation/remediation project are critical to developing the most technically feasible and cost-effective design. Site-specific aspects include geology, topography, climate, drainage, surface and groundwater hydrology, regional water resources, water quality, public opinion, regulatory climate, and cost.

C. NRCE Facilities

Administration and engineering analyses can be coordinated and conducted at all of the following NRCE locations:

Colorado Office
131 Lincoln Ave., Ste. 300
Fort Collins, CO 80524
(970) 224-1851

California Office
1250 Addison St., Ste. 204
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Albuquerque Office
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P.O. Box 5260
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NRCE's Geographic Information System (GIS) and Computer-Aided Drafting (CAD) department produces professional plans, maps, and decision support information, as well as data transfer, relational database management, map overlay, display query, interactive graphics editing, and customized maps for engineering design and support. The CAD system utilizes AutoCAD Release 14. ArcView 3.0 GIS, including the ArcView Spatial Analyst, is used for vector, raster, and grid based data analysis. ArcCAD GIS, running within the AutoCAD environment, is used to create and analyze a wide variety of vector-based data and to create presentation maps for these coverages. ArcView and ArcCAD both use the ARCINFO data format and can directly transfer between versions of PC, NT, and Unix ARCINFO. GIS integrates the graphical data in a relational database environment and provides professionals with automated floodplain maps, water resource maps, base maps, land use maps, litigation maps, design drawings, planning and decision support maps, as well as customized information. The GIS department provides a full range of graphical and non-graphical information for precision engineering, design, planning, and evaluation.

The NRCE software library contains a broad range of application packages. The staff has extensive programming skills and capabilities to custom design or adapt commercially available or public domain computer programs. Well-tested software packages that meet industry standards and testing requirements have been purchased. In addition to various spreadsheets, communications, database, graphics, and word processing software, software and computer aided design packages developed or employed by NRCE by category include:

1. **Hydrologic and Hydraulic**
    a. Army Corps HEC-1 (Flood hydrograph package)
    b. Army Corps HEC-2 (Water surface profile)
    c. Army Corps HEC-3 (Reservoir system analysis for conservation)
    d. Army Corps HEC-4 (Monthly streamflow simulation)
    e. Army Corps HEC-5 (Simulation of flood control and conservation system)
    f. Army Corps HEC-6 (Sediment transport model)
    g. Army Corps COED (Corps of Engineers Editor)
    h. Army Corps HECDDS (Data storage system)
    i. Multiple Linear Regression Program
    j. Soil Conservation Service TR-20 Project Formulation, Hydrology
    k. Drainage basin depletion and virgin flow analysis
    l. Reservoir operations analysis and design
    m. Pipe network design (Hardy-Cross)
    n. Dam Operation and Hydropower Generation Optimization

2. **Groundwater Analysis**
    a. Well field design and simulation
    b. Pump test analysis
    c. Conjunctive use modeling
    d. MODFLOW regional groundwater flow model
    e. SUTRA groundwater contaminant transport model

3. **Agricultural System Design**
   a. Drainage spacing and design
   b. Irrigation system design
   c. Crop yield prediction
   d. Crop consumptive use
   e. Canal seepage analysis
   f. Pipeline network design (optimization approach)

NRCE possesses both streamflow and climatic data for seventeen western states. The data are from Earthinfo Inc., and utilize CD-ROM technology. With "Hydrodata", NRCE has access to U.S. Geological Survey (USGS) daily flow and water quality data, as well as annual peak flow data for all USGS gages in the seventeen western states. "Climatedata" allows access to maximum and minimum temperature, evaporation, and snowfall on a daily basis, and precipitation on both a daily and hourly basis for all stations and years computerized by the National Climatic Data Center.

NRCE is a member of the National Association for Water Data Exchange (NAWDEX) and subscribes to the Water Data Storage and Retrieval System (WATSTORE) maintained by the USGS. The firm also has access to and use of the services provided by the Environmental Protection Agency (EPA) through their STORET database.

Complete drafting facilities and libraries are maintained in Fort Collins and in Berkeley. The Berkeley office is close to the Water Resources Center Archives and other library facilities available at the University of California, Berkeley. It is also close to the USGS, Earth Resource Library in Menlo Park, further expanding the research capabilities of NRCE staff members. The Fort Collins office is in close proximity to Colorado State University, which maintains a federal repository, as well as special water resources collections.

NRCE TECHNICAL PERSONNEL

Name	Degree			Major	Professional Registration	Years of Experience
	Ph.D.	M.S./ M.E.	B.S./ B.A.		P.E./ P.G.	Experience
Mesghinna, Woldezion	✓			Irrigation & Drainage Engineering		
		✓	✓	Civil Engineering	✓	31
Safadi, Assad	✓			Agricultural & Irrigation Engineering		
		✓	✓	Soils and Irrigation		18
Hamai, Paul		✓	✓	Civil Engineering	✓	13
Allen, L. Niel	✓			Civil Engineering		
		✓	✓	Agricultural & Irrigation Engineering	✓	24
Babic, Marijan	✓	✓	✓	Civil Engineering	✓	19
Hanlin, Todd		✓	✓	Civil Engineering	✓	18
Laing, David			✓	Civil Engineering		15
Leutheuser, Rob			✓	Resource Management		31
Crouch, Thomas			✓	Geology		39
Al-Hassan, Ayman		✓	✓	Chemical Engineering		23
Wessman, Eric			✓	Agricultural Engineering	✓	
			✓	Range Land Management		18
Tzou, Chung-Te	✓			Agricultural & Biosystems Engineering		
		✓	✓	Irrigation Engineering	T	19
			✓	Physics	✓	
Myer, David Kyle		✓	✓	Civil Engineering		8

APPENDIX 2

The Lower Colorado River

2. THE LOWER COLORADO RIVER

The Colorado River originates in northern Colorado, with its headwaters located in the western part of Rocky Mountain National Park. The river is joined by several major tributaries, including the Green River, which originates in the Wind River Mountains of Wyoming. The Colorado River Basin encompasses portions of seven Western states: Colorado, Wyoming, Utah, New Mexico, Nevada, Arizona, and California. Spring runoff generally begins in April and continues until the month of July.

Just below Lake Mead, the Colorado River forms the boundary between Nevada and Arizona, and further downstream it serves as the boundary between California and Arizona. The Colorado River then enters Mexico just downstream of Yuma, Arizona. After crossing portions of Mexico, it finally empties into the Gulf of Mexico.

There are three major facilities that store and regulate flows on the Lower Colorado River: Hoover, Davis, and Parker Dams. They are located entirely within Nevada, Arizona, and California. Prior to the construction of the first dam, the Colorado River flowed wildly and changed course frequently, and the flood plains of the lower Colorado River were subject to fierce floods. These floods reached flow levels above 200,000 cubic feet per second (cfs) in the years of 1862, 1884, and 1921, while flood flows over 100,000 cfs were common, occurring approximately every other year (USGS, 1955). In fact, due to abnormally high flows received from the Gila River, the Colorado River's course was so drastically changed that it emptied into the Imperial Valley during the period 1905 to 1907. It was from this enormous flood that the Salton Sea was created.

The long-term average natural flow, or undepleted flow, represents the state of the river flow prior to man's water use. The estimated natural flow of the Colorado River at Lee's Ferry, is about 15.2 million acre-feet per year, according to the United States Bureau of Reclamation (USBR, 2000). The annual natural flow ranges from 5 million acre-feet in 1977 to 24 million acre-feet in 1983. As most of the river watershed is located in the arid and semi-arid regions, the flow of the Colorado River varies significantly from year to year. The entire Colorado River Basin area is about 242,000 square miles, with the unit runoff for the entire area being 1.1 inch per unit area. Most of the river flow is generated at the headwaters of the basin, where an average of more than 40 inches of precipitation occurs annually. Lower areas of the basin receive less than an average of 5 inches per year of precipitation.

Historical flow data demonstrates that prior to the construction of major dams and reservoirs, destructive floods of high magnitude occurred frequently. In the early 1930s, the U.S. government began constructing major dam and storage facilities, the first being Hoover Dam which thereby created Lake Mead. After completing this project in 1935, the regulation of the Colorado River was greatly enhanced. Once Hoover Dam was put into operation, the most devastating floods were controlled and the peak release annual discharge did not exceed 40,000 cfs. The effects of Hoover Dam on the annual average flows of the Colorado River near Topock, Arizona (USGS gage # 0942400) are illustrated in Figure 1. The average flow became 9.2 million acre-feet per year, from 1935 through 1981. The storage capacity of Lake Mead at the time of Hoover Dam's completion was about 30 million acre-feet.

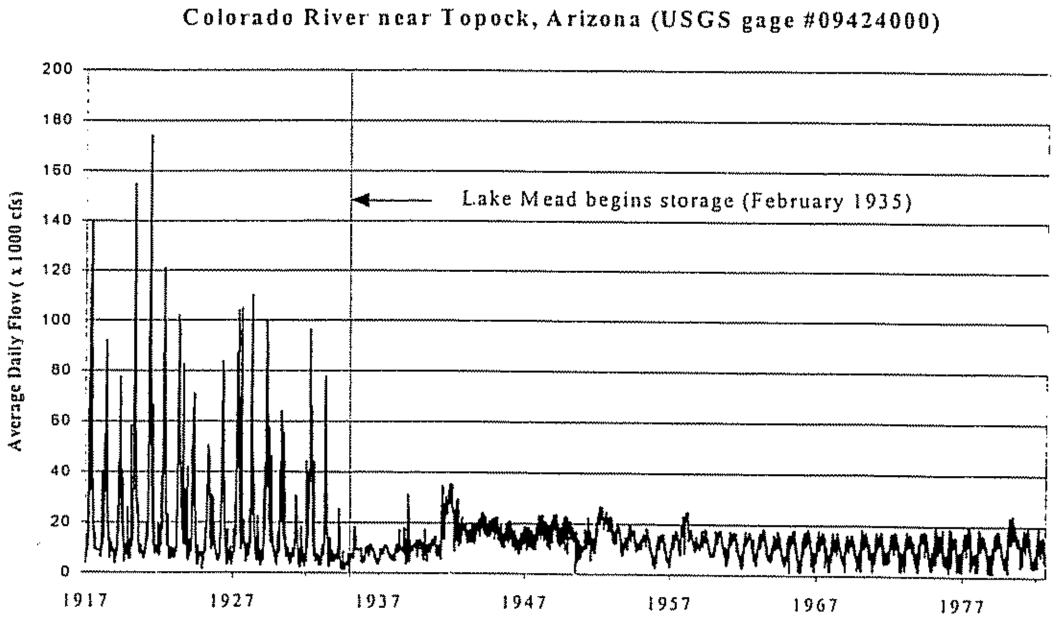

Figure 1 The Effects of Hoover Dam on the Annual Average Flows of the Colorado River Near Topock, AZ.

Prior to the construction of Hoover Dam, the Colorado River's average flow varied substantially both from month to month and from year to year. After Hoover Dam was built, the variation in monthly river flows became relatively constant from year to year. By storing high spring flows, it became possible to supply irrigation water to the large irrigation districts as well as municipal water to millions of people in southern California and central Arizona.

Parker Dam was built in 1938 and further increased control of the river. Once constructed, these two dams provided a relatively assured water supply and greatly limited damage from flooding. However, there are very few tributaries that contribute significant, unregulated flow. The Bill Williams River, with its very erratic flow regime, enters the Colorado River at Lake Havasu, and the Gila River, which drains large portions of Arizona joins the Colorado River close to Yuma, Arizona.

In between Hoover Dam and Parker Dam is the third major structure built on the lower Colorado River: the Davis Dam, which formed Lake Mohave. This dam controls the flow of the Colorado River's main stem and is used to re-regulate the flows released from Lake Mead and provide sufficient head for hydropower production at the Davis Power Plant. Moving further downstream from the Davis Dam is Lake Havasu, created by Parker Dam. In addition to flood control, Lake Havasu acts as the forebay for the Central Arizona Aqueduct and the Colorado River Aqueduct, which is owned and operated by the Metropolitan Water District of Southern California.

Together the three reservoirs have a usable storage capacity of about 28.6 million acre-feet. The total usable storage in the Lower Basin states of California, Arizona, and Nevada provides an equivalent of a two-year undepleted flow of the Colorado River. The water supply for IID, the other irrigation districts in Arizona and California, and the required water releases for Mexico and power generation are primarily dependent on the availability of storage in those Lower Basin reservoirs. Given the very high variability of the Colorado River flow from year to year, the nearly 29 million usable storage capacity available for the Lower Basin water users is relatively self-assuring.

In addition to the three major storage reservoirs on the main stem of the lower Colorado River, there are a number of diversion dams that exist mainly to divert water to irrigation districts in Arizona, California, and Mexico. Among the primary diversion facilities downstream of Parker Dam are: Head Gate Rock Dam, which controls and diverts water for the Colorado River Indian Reservation Irrigation Project (Arizona); Palo Verde Diversion Dam, which controls and diverts water for the Palo Verde Irrigation District (California); and Imperial Dam, which serves water users in Yuma, Arizona; Mexico; IID; and Coachella Valley Water District of California. It should be noted that IID was diverting water to irrigate hundreds of thousands of acres of land prior to the construction of the major dams on the Lower Colorado River.

APPENDIX 3

IID's Water Rights on the Colorado River

3. IID'S WATER RIGHTS ON THE COLORADO RIVER

IID was organized under the California Irrigation District Act in July 1911. The District was organized by acquiring the rights and properties of the California Development Company and its subsidiary Mexican company. During the early 1900s no major dams or reservoirs existed; therefore, water users were primarily dependent on the unregulated seasonal flows of the Colorado River and its tributaries.

In the early 1900s, the current federal laws governing water rights of the Colorado River were not yet in place. In fact, there was no regional or interstate water rights compact apportioning the Colorado River. The basic water rights laws of that time were doctrines of prior appropriations applicable within a given state. Because of this, it became prudent for both the Upper and Lower Basin states to apportion the Colorado River water through an interstate compact. The four Upper Basin states, Colorado, Wyoming, New Mexico, and Utah, and the three Lower Basin states, Nevada, Arizona, and California, signed what is known as the Colorado River Compact of 1922. The fundamental principle of the Compact is that the upper and Lower Colorado River states equally apportion water rights such that each side receives an exclusive beneficial use of 7.5 million acre-feet of consumptive use per year in perpetuity. The dividing line for the Colorado River between the Upper and Lower Basin states is Lee's Ferry. The U.S. government, through the Boulder Canyon Project Act, also required that California pass an act limiting itself to 4.4 million acre-feet per year consumptive use. In addition to the 4.4 million acre-feet, California had the right to use up to one half of the unappropriated surplus flow. Within seven years after the Upper and Lower states signed the Colorado River apportionment Compact, the state of California passed the required act, limiting its apportioned use to 4.4 million acre-feet. In 1944, the United States and the Republic of Mexico signed a treaty for Mexico to receive 1.5 million acre-feet of Colorado River water per annum.

The construction of major facilities, including Hoover Dam, its associated hydro-power plant, and the All American Canal, were authorized as part of the Boulder Canyon Project Act passed by Congress in December of 1928. The Boulder Canyon Project Act also required the Lower Basin states to enter into water delivery contracts with the U.S. Secretary of the Interior. As part of the Act, California would receive 4.4 million acre-feet of water per year of the total amount of water apportioned to the Lower Basin states, plus one half of the excess water agreed by the Lower Basin states. Arizona would receive 2.8 million acre-feet of water, plus one half of the surplus water as determined by the Lower states, and Nevada would receive 300,000 acre-feet annually. Even though the states never reached a final agreement on the proposed apportionment, in 1964 the U.S. Supreme Court decided in the case of <u>Arizona v. California</u> that the Boulder Canyon Project Act authorized the Secretary of the Interior to deliver water in accordance to the apportionment. In essence, there was no need for the Lower Basin states to agree on the proposed apportionment of their 7.5 million acre-feet of the Colorado River water, since Congress had done it for them.

The Secretary of the Interior requested California to further apportion its 4.4 million acre-feet among its water users. In 1931, in response to the Secretary's request, a Seven-Party Agreement to apportion and prioritize their water rights was created. The signatories to the California Seven-party Agreement are:

1. Palo Verde Irrigation District
2. Yuma Project
3. Imperial Irrigation District
4. Coachella Valley County Water District
5. Metropolitan Water District
6. City of San Diego
7. County of San Diego

Table 1 depicts the water apportionment and priorities of the 1931 California Seven-party Agreement. As shown in Table 1, the irrigation districts receive the first 3.85 million acre-feet, as well as use of water for an additional 16,000 acres. (Coachella later subordinated its Priority 3 right to IID in a compromise agreement.) If one adds the next apportionment by priority, the 550,000 acre-feet belonging to the Metropolitan Water District, the total California apportionment of 4.4 million acre-feet per year will be utilized. In other words, if California were to abide by the 4.4 million acre-feet apportioned to it as part of the Boulder Canyon Project Act of 1928, the only recipients of water would be the four agricultural users and the Metropolitan Water District of Southern California (and the latter would only be able to fill half the capacity in its Colorado River Aqueduct).

Table 1 Priority Established by the California Seven-Party Agreement for Water Apportionment.

Priority	Description	Acre-feet per year
1	Palo Verde Irrigation District gross area of 104,500 acres	
2	Yuma Project not exceeding a gross area of 25,000 acres	
3(a)	IID and lands in Imperial and Coachella Valleys to be served by the All-American Canal	3,850,00
3(b)	Palo Verde Irrigation District 16,000 acres of mesa lands	
4	MWD and/or the City of Los Angeles and/or others on the coastal plain	550,000
5(a)	MWD and/or the City of Los Angeles and/or others on the coastal plain	550,000
5(b)	City and/or County of San Diego	112,000
6(a)	IID and lands in Imperial and Cachella Valleys	300,000
6(b)	Palo Verde Irrigation District 16,000 acres of mesa lands	
7	Agricultural Use	All remaining water

In 1979, IID had a "perfected" right confirmed amounting to 2.6 million acre-feet annually by a supplemental decree in the *Arizona v. California* case. This perfected right is a state water right, estimated based on the lands that were actively irrigated in the year 1929. The 2.6 million acre-feet is commensurate with the lands that were actually receiving irrigation water in IID as of June 25, 1929, which amounts to 424,145 acres. The essence of the present perfected right is that during water shortages the water rights that should be satisfied first are the perfected rights. Thereby, the perfected water rights of IID are not subject to U. S. Department of Interior limitations. The perfected right is not a limitation on IID's usage, but is simply a priority right granted over other non-perfected users.

In addition to the Indian Reservations in the Lower Basin that have present perfected rights, the Palo Verde Irrigation District has a perfected right of 219,780 acre-feet annually to satisfy the consumptive use for 33,604 acres. Likewise, the Yuma Project has a perfected right to 38,270 acre-feet per year to supply the consumptive use of 6,294 acres of irrigated land.

APPENDIX 4

CIMIS Data

4. CIMIS DATA

The three California Irrigation Management Information System (CIMIS) weather stations in IID are Calipatria/Mulberry (#41), Seeley (#68), and Meloland (#87). They are shown in Figure 1 along with the shaded areas indicating the region each of the stations represents. The stations are located in or near an irrigated environment with a well-maintained grass pasture. Their installation dates, latitudes, longitudes, and elevations are as follows:

Station	Begin Date	Latitude (°)	Longitude (°)	Elevation (ft)
Calipatria/Mulberry	7/17/1983	33.04 N	115.5 W	-110
Seeley	5/29/1987	32.76 N	115.7 W	40
Meloland	12/12/1989	32.81 N	115.4 W	-40

The weather data from the CIMIS stations may be downloaded on-demand electronically by users over telephone lines. The stations' data loggers store in memory hourly weather parameters of solar radiation, air temperature, relative humidity, wind speed and direction, and precipitation after they have averaged the minute-to-minute measurements. The collected parameters are then used to compute grass reference evapotranspiration (ET_o) on an hourly basis using the CIMIS' version of the Penman equation (Penman, 1948) as modified by Pruitt and Doorenbos (proceeding of the International Round Table Conference on "Evapotranspiration", Budapest, Hungary, 1977). The hourly ET_o values were summed to produce the daily ET_o values reported by CIMIS.

For this study, the daily raw meteorological data from the three CIMIS stations were downloaded directly from the web site of the University of California Statewide Integrated Pest Management (IPM) Project Weather Database at: www.ipm.ucdavis.edu/WEATHER/ wxretrieve.html for the study period of 1988 to 1997. The meteorological data were screened for data quality and were pre-processed by IPM. All of the questionable, flagged, or missing data parameters from CIMIS were replaced with good available data from other nearby CIMIS stations or other weather stations. The filled in data for each of the three CIMIS stations comprised only about 2-3% of the total data.

The average weather parameters collected by the three CIMIS stations for the period 1990 to 1998 are plotted in Figures 2 through 6. The period was selected as 1990 to 1998 because the Meloland Station was installed in December 1989. The plotted weather parameters are average monthly maximum and minimum air temperatures, relative humidity, average solar radiation, average wind speed, and precipitation.

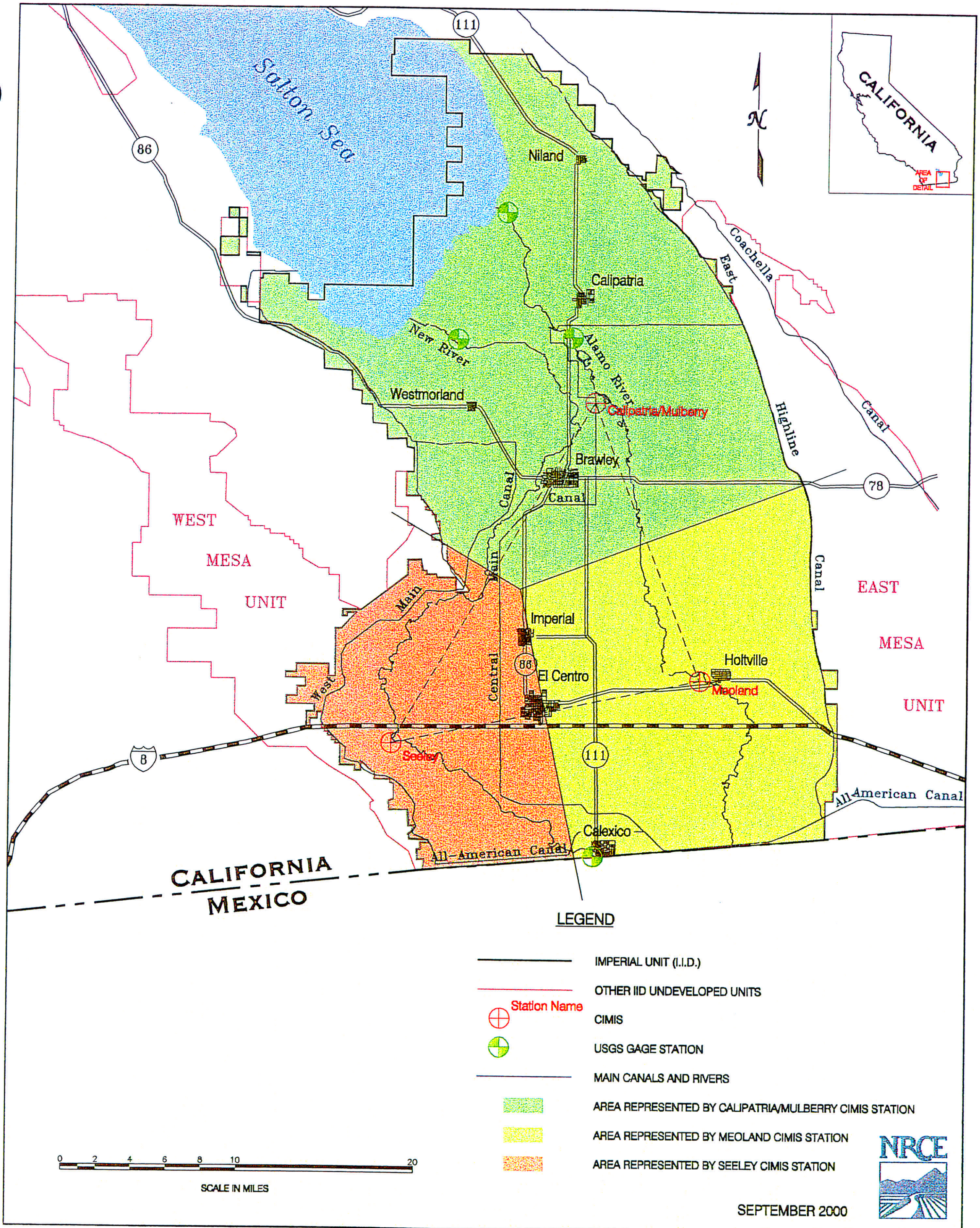

Figure 1 Location Map of the CIMIS Stations and the Area Represented by Each Station as Determined from the Thiessan Polygon Method.